WASTE MANAGEMENT

1 INTRODUCTION

This chapter presents methods for evaluating emissions-reduction options for the waste management sector. The primary sources of emissions in this sector include landfills and wastewater treatment. Options for mitigating emissions from livestock manure are discussed in Chapter X.

Landfills: Methane is emitted from landfills as the result of the anaerobic decomposition of organic wastes. The methane migrates through the waste laterally and vertically, eventually escaping to the atmosphere. Landfills are a major global source of methane, contributing between 20 and 60 Tg of methane annually (USEPA, 1994). The major uncertainties in these estimates include the amount of organic material actually disposed of in landfills by different countries, the portion of the organic waste that decomposes anaerobically, and the amount of methane generated per unit of decomposed waste. About two-thirds of methane emissions from landfills come from the more developed countries of the world, another 15% from countries with transitional economies, and 20% from developing countries (USEPA, 1994).

The primary method for reducing methane emissions from existing landfills is to collect and combust the landfill gas. Diverting organic refuse to other disposal and treatment options and away from landfills can reduce future emissions.

Wastewater Treatment: Wastewater and sludge, its residual solids by-product, produce methane emissions if they are stored or treated under anaerobic conditions (in the absence of oxygen). In some cases this methane is collected and used or flared, but in most circumstance the methane produced is released to the atmosphere. Although data are very limited, current global estimates of methane emissions from the management of residential, commercial, and industrial liquid and water-carried wastes are about 20 to 25 Tg per year (based on calculations of the organic content of wastewater in different regions). These estimates are no better than $\pm$50%.

The amount of methane emitted depends on the organic loading in the wastewater (measured as biochemical oxygen demand, or BOD) and the extent to which the organic material degrades under anaerobic conditions. The majority of the methane emissions from wastewater are believed to originate in developing countries, where domestic sewage and industrial waste streams are often unmanaged or maintained under anaerobic conditions without control of the methane (USEPA, 1993b). However, much uncertainty remains regarding the emissions rates from wastewater treatment conditions found in many developing countries. Consequently, the emissions reduction that could potentially be achieved is not well quantified.

The most effective technique for reducing these emissions is to implement effective aerobic wastewater treatment systems. Such systems produce other significant human health and environmental benefits and are consequently also desirable for reasons other than methane mitigation. It is also feasible to use anaerobic treatment systems and recover and combust the methane produced.

2 MITIGATION OPTIONS

2.1 Landfills

There are two approaches to reducing methane emissions from landfills: (1) the methane generated in landfills can be recovered and used to produce energy; and (2) the quantity of landfilled waste can be reduced through source reduction, recycling, and other waste-management practices. These approaches, summarized in Table 1, are presented briefly below (see USEPA (1993a) for a more detailed discussion of the options).

2.1.1 Recovery and use of landfill gas

Landfill gas-recovery technologies have been demonstrated and are in use in several countries and there is great potential for expanding these technologies in both developed and developing countries. The landfill gas is extracted through a series of wells drilled into the refuse. Negative pressure is applied to the wells to extract the gas, which is collected through a system of pipes. The gas is then processed to remove water and various contaminants. Between 50 and 85% of the landfill gas generated can typically be recovered from landfills, with well-designed projects achieving almost complete gas recovery.

The landfill gas can be used as an energy source, which offsets the cost of recovering the gas. Options for using the gas include:

- **Electricity Generation and Co-Generation.** The recovered methane can be used to power an electric generator, with the generated electricity used on-site or sold to others for use. The waste heat produced during electrical generation can also be recovered and used for local heating needs. Electricity generation requires relatively large amounts of landfill gas and is therefore suitable for larger landfills. Economic viability depends primarily upon the price at which the electricity can be sold. Historically, more than 50% of landfill projects worldwide have been for electricity generation (Richards, 1989), including projects in the U.S., U.K., Germany, Brazil, India, and the Netherlands. The Global Environment Facility (GEF) Fund is planning to undertake a project in Lahore, Pakistan, that will recover

over 14 million m^3 per year of landfill gas (over a period of five years) from a large sanitary landfill designed to handle 730,000 tons of waste disposed of annually by the city's 5 million inhabitants (USEPA, 1993b).

Table 1.
Summary of the Technical Options for Reducing Methane Emissions from Landfills

Considerations	Methane Recovery and Utilization	Alternative Waste Management Practices
Recovery/Reduction Techniques	· Recovery Wells · Collection Systems	· Source Reduction · Incineration · Composting
Gas Use/Combustion Options	· Electricity Generation · Natural Gas Supply · Flaring	-
Availability	· Currently Available	· Currently Available
Capital Requirements	· Medium	· Low/Medium
Technical Complexity	· Medium/High	· Low/Medium
Applicability	· Existing and New Landfills · Nearby Gas Use · Capital- and Technology-Dependent	· Widely Applicable
Methane Reductions[a]	· 50-90%	· Up to 100% of future emissions[b]

a) Reductions that may be achieved at individual landfills.
b) Does not reduce emissions from existing landfills.

Source: USEPA (1993a)

- **Medium Btu Gas.** Landfill gas can be used directly as a medium Btu fuel to provide heating, cooling, or steam for industrial processes. Recovered landfill gas is already profitably used as a boiler fuel and for other industrial and residential applications in a variety of countries, including the U.S., Brazil, South Africa, and Chile.

- **Natural Gas Supply.** Landfill gas can be processed to produce "pipeline quality" gas (over 95% methane) with minimal impurities by removing moisture, carbon dioxide (CO_2), and hydrogen sulfide (H_2S). The gas must also be compressed at a certain minimum pressure to be injected into a pipeline or distribution system. There are several such projects in the U.S. that provide gas to local gas distribution systems.

2.1.2 Alternative waste-management strategies

A variety of technical options applicable in the near and longer term can reduce the landfilling of wastes through source reduction and recycling of organic materials. Paper products, for example, comprise a significant portion of solid waste in developed countries (e.g., 40% in the U.S.) and a growing portion of solid waste in some urban centers in developing countries (typically 5 to 20%) (USAID, 1988; Vogler, 1984). Paper products can be recycled into a variety of products and the markets for the recycled products are, in most cases, identical to those for virgin paper products. Waste paper-recycling processes range in technical complexity and include technologies as simple as hand-operated baling presses.

Composting is another promising waste management option that limits methane generation by reducing the amount of waste landfilled. Composting is applicable in the near and longer term, particularly in developing countries where the organic and moisture contents of municipal wastes are often high. The economics of composting projects can be favorable if a market exists for the compost. Markets often depend on the demand for fertilizer and are generally favorable in arid regions and other areas where organic soil supplements are needed.

Incineration of wastes is increasingly used in developed countries to reduce quantities of landfilled wastes, often combined with energy recovery from the combustion process. The costs of incineration are justified based on the increasing costs of handling municipal solid wastes. While there is potential for this technology to expand in developed countries, there is a much lower potential in developing countries because the wastes are frequently too moist for economically viable operations (USAID, 1988).

The preferred approach for reducing methane emissions from landfills for an individual country will depend on past waste-disposal practices. Countries that have already disposed a significant amount of organic material in landfills should consider landfill gas recovery and utilization to reduce the emissions from these existing landfills. Landfill gas recovery is the only feasible method of reducing these emissions. Countries that are only now beginning to dispose of organic wastes in landfills should minimize the amount of organic material placed in landfills. By minimizing such disposal, future emissions will be reduced. Because some organic material will likely continue to be disposed in landfills, all new landfills should be designed with gas-collection and utilization systems.

Reducing the landfilling of organic materials and landfill gas collection have benefits in addition to reduced methane emissions including the following:

- decreased safety hazards from the migration of potentially explosive methane beyond the landfill boundaries;

- reduced odor problems from landfills; and

- reduced emissions of air pollutants such as volatile organic compounds (VOCs) and air toxics that adversely affect air quality and human health.

2.2 Wastewater Treatment

Although the factors affecting methane emissions from wastewater treatment remain very uncertain, it is generally believed that providing effective aerobic wastewater treatment will help reduce emissions. If anaerobic treatment is preferred to aerobic treatment, capturing and using the methane produced during treatment would also reduce emissions. These two approaches are summarized as follows (additional description is provided in USEPA, 1993a):

- **Aerobic Treatment:** Aerobic treatment includes aerobic primary and secondary treatment and land treatment. Aerobic primary wastewater treatment is achieved by sustaining sufficient oxygen levels during the primary phase of wastewater treatment (i.e., in oxidation ponds), using controlled organic loading techniques or providing oxygen to the wastes through mechanical aeration. Aerobic secondary treatment consists of stabilizing wastewater by prolonging its exposure to aerobic microorganisms which are either suspended (due to mechanical aeration) or attached to a fixed bed or a rotating cylinder. Finally, land treatment involves applying wastewater to the upper layer or the surface of soil, which acts as a natural filter and breaks down the organic constituents in the wastewater.

- **Recovery and Utilization of Methane from Anaerobic Digestion of Wastewater or Sludge:** If the wastes are treated (digested) under controlled anaerobic conditions, the resulting methane and other gases can be recovered and utilized as an energy source to heat the wastewater or sludge-digestion tank, produce power in other parts of the plant, or sell to nearby homes, industrial plants, or utilities. Flares are frequently used as part of these operations to dispose of excess methane.

Although the costs and benefits of these mitigation approaches remain to be assessed, initial research has indicated that improved wastewater treatment has a variety of benefits in addition to reducing methane emissions, including:

- reduction in the risk of water-borne diseases (Loehr, 1984);

- reduced eutrophication of receiving waters, which can be caused by high levels of phosphorus and/or nitrogen;

- elimination of odors from standing wastewater; and

- production of treated wastewater and sludge for various uses (e.g., recharging ground water, irrigation, soil enrichment, production of potting mixes and topsoil, turf production and maintenance, reclamation of disturbed lands).

In the past, the benefits of reduced disease risk and protection of receiving water quality have been the controlling factors in the design and deployment of wastewater treatment systems. Improved wastewater treatment is likely to be desired for these reasons in most cases where untreated wastewater is producing methane emissions.

3 OVERVIEW OF THE MITIGATION ASSESSMENT PROCESS

The following four steps are recommended for performing a mitigation option analysis.

Step 1: Develop Scenario Inputs. The purpose of this step is to prepare inputs, such as the number of landfills and the volume of waste stream targeted for diversion away from landfills. These will serve as inputs for the preparation of both baseline and mitigation scenarios.

Step 2: Identify Target Sub-Groups to be the Focus of the Emissions-Reduction Effort and Refine the Emissions Estimates for the Sub-Group. The purpose of this step is to focus the analysis on those portions of the GHG source that are amenable to control. The target sub-groups are selected based on the applicability of the mitigation options for the source. A more detailed baseline emissions estimate is then developed for the target sub-groups. This detailed baseline will be used to estimate the emissions reduction that can be achieved.

Step 3: Evaluate the Mitigation Options for the Sub-Group. The purpose of this step is evaluate the impacts that the mitigation options have on the emissions and other characteristics of the target sub-group.

Step 4: Develop Baseline and Mitigation-Emissions Scenarios. Using the information generated in Steps 1, 2 and 3, baseline and mitigation emissions scenarions may be developed for landfills and wastewater treatment.

4 SCENARIO INPUTS

The IPCC/OECD emissions inventory guidelines identify the inputs needed to estimate methane emissions for 1990. Scenarios of future emissions, with and without the implementation of mitigation options, may be developed by forecasting the key variables that drive the emissions.

Methane emissions from landfills are driven principally by the amount of degradable organic material disposed in landfills. Future emissions depend both on the amount of waste already placed in landfills and the amount placed in landfills in the future. Therefore, future waste disposal rates must be estimated to forecast future emissions. Future disposal rates will depend on the amount of waste generated and the portion of the waste placed in landfills. Per capita waste-generation rates have been found to be dependent on consumer preferences and industrial activity. Because per capita income has been found to be one predictor of waste-generation rates, the data presented in the IPCC/OECD emissions inventory method can be used to estimate future per capita waste-generation rates as per capita incomes increase. The implications of changes in landfilling practices should be considered in the baseline scenario if such changes are expected.

Like emissions from landfills, methane emissions from wastewater treatment are driven principally by the amount of organic material that is treated anaerobically. The IPCC/OECD emissions inventory method recommends that the emissions be estimated separately for municipal and industrial wastewater. The amount of organic material in municipal wastewater nationally may be estimated as the population times a per capita waste-generation rate in units of BOD (i.e., kg BOD per capita-day). Regional rates of BOD generation per capita are given in the IPCC/OECD method, which are adequate for assessing the rough magnitude of emissions. More precise locally derived data would be preferred.

Organic material in industrial wastewater may be estimated based on production in several key industries. As with municipal wastewater, the IPCC/OECD method presents factors for estimating organic material in industrial wastewater.

To estimate methane emissions, the portion of the municipal and industrial wastewater that is treated anaerobically must be estimated. There is very little data on this important parameter, and additional assessments are required to improve the basis for making the estimates. At a minimum, the wastewater generated should be allocated into aerobic and anaerobic major treatment categories, such as:

- Aerobic: open pits/latrines; shallow ponds; ocean discharge; river discharge; and aerobic primary and secondary treatment systems.

- Anaerobic: deep ponds; anaerobic digesters; and septic tanks.

For each of the categories, an estimate is needed of the uncontrolled methane emissions that result per unit of BOD treated. Field measurement data are lacking for this parameter as well. Consequently, field measurement programs are needed to quantify current emissions and emissions reductions achievable by switching among treatment regimes.

5 ANALYSIS OF MITIGATION OPTIONS

The analysis of options for reducing methane emissions from landfills can proceed in two directions: gas recovery and waste diversion from landfills. The following approach is recommended for evaluating gas recovery.

- **Identify Landfills At Which Gas Recovery Is Attractive.** The purpose of this step is to identify the population of landfills at which gas recovery and use is feasible and economically attractive. Experts in landfill gas recovery and use should be consulted to define those landfill characteristics that make landfills attractive for gas recovery. Generally, landfills should be relatively large (e.g., have at least 1 million metric tons of waste in place) and should be able to support the drilling of wells into the refuse (i.e., the refuse and the soil should be stable and not saturated with water). The actual landfill-gas recovery plant size will depend on the gas production rate, costs of gas collection and utilization, and the value of the energy derived from the gas in the specific circumstance.

- To the extent possible, data on the individual landfills should be obtained, e.g., from landfill operators. For this set of landfills, detailed information on waste characteristics should be obtained for purposes of developing more detailed estimates of methane emissions. Test wells at selected landfills would be useful for verifying the emissions estimates for this set of landfills.

- **Evaluate Gas Recovery Projects.** For the targeted set of landfills, the costs and benefits of landfill gas recovery projects should be assessed. The costs of recovering the gas may be estimated using engineering cost estimates, such as those in USEPA (1993c), or similar country-specific cost factors. The amount of gas expected to be recovered may be estimated as a portion of the estimated emissions (e.g., 75% of emissions). The revenue from using the collected gas should be estimated based on the quantity of gas collected and the local value of the gas. A discounted cash flow analysis can then be done to identify the cost or benefit per unit of landfill gas emissions avoided.

- **Estimate Emissions Reductions.** Based on the evaluations of the gas recovery projects, the extent to which landfill methane emissions can be reduced from the targeted landfills can be estimated. The cost of reducing emissions by various amounts can be estimated as well using the results of the discounted cash flow analysis.

In addition to evaluating opportunities for recovering landfill gas, options for diverting waste away from landfills can also be considered. The major alternatives of recycling, source reduction, composting, and incineration may be examined. The impact on future methane emissions would be estimated based on the amount of degradable organic carbon (DOC) diverted away from landfills over time. The general approach to this assessment would include the following:

- Identify the component of the waste stream targeted for diversion away from landfills (e.g., paper).
- Identify options for managing the targeted portion of the waste stream (e.g., recycling).
- Estimate costs and benefits of diverting the waste.
- Estimate the amount of waste diverted over time and the avoided methane emissions from the avoided landfilling of the waste.

6 CONSTRUCTING BASELINE AND MITIGATION SCENARIOS

The purpose of this step is to estimate emissions with and without the implementation of selected mitigation options. It is recommended that these scenarios be developed in detail for the target sub-groups for specific years, such as 2000, 2010, and 2025. The same models or techniques should be used to estimate both the baseline and the mitigation scenarios for each of the sources. The IPCC/OECD emissions inventory methods are recommended.

The inputs needed to develop the scenarios are discussed above. The underlying forecast variables used throughout the analysis should be used as the basis for the future estimates. Ranges of assumptions should be developed for those parameters or estimates that are uncertain. The implications of the uncertainty should be propagated throughout the assessment.

7 MITIGATION POLICIES

Both landfills and wastewater treatment facilities often fall within the purview of local, regional, or national governments. Waste disposal and treatment services are often provided directly by government agencies or are regulated activities of private entities. Consequently, implementation of emissions-reduction options for these sources will likely involve direct action on the part of governments.

7.1 Landfills

Landfill gas recovery and use can be implemented directly by government agencies that own and operate landfills. The technologies are well-known and the energy derived from the gas can be used to produce electricity or for other purposes. In cases where landfills are owned privately, options for promoting gas collection and use may include requiring gas collection and use by regulation and providing incentives for gas recovery and use, e.g., in the form of subsidies or guaranteed energy-purchase contracts.

Programs to divert waste from landfills would similarly be implemented by government agencies. Examples of approaches include the following:

- increase landfill disposal costs for certain waste streams that can be diverted;
- require paper products to contain a minimum percentage of recycled post-consumer fiber;
- implement waste stream separation, either by waste generators or post-collection; and
- set source reduction and recycling targets for communities to attain.

7.2 Wastewater Treatment

Despite a widespread awareness of the health risks caused by poorly managed waste streams, many countries lack the resources with which to build a wastewater treatment infrastructure. Generally, wastewater treatment activities fall under the responsibility of local, regional, or national governments. Consequently, government initiatives to provide or improve wastewater treatment practices are likely to be called for. The broad government options for promoting the reduction of this source of methane are as follows:

- **Promote, Assist, or Provide for the Development of Comprehensive Wastewater Management Policies, Infrastructure, and Treatment Systems:** In areas where no wastewater treatment systems exist, assistance could include policy development, funding and technological aid for the development of municipal collection and drainage systems, construction of municipal and industrial wastewater and sludge treatment facilities, and operation training programs.

- **Assist in the Design and Development of Smaller-Scale, Community Wastewater Management Systems:** Small communities, where domestic wastes are often washed into streams or allowed to collect in gutters, latrines, or ponds, may account for a large part of methane emissions from developing countries. While complex treatment systems may not be feasible in such areas, smaller scale projects designed to divert waste streams into designated ponds and maintain aerobic or facultative (aerobic in the upper layers) conditions could reduce both methane emissions and health risks. Additional benefits of such projects may include reduced odors and the potential for using stabilized sludge as fertilizer.

- **Expand Management Infrastructure to Serve Entire Population:** Some regions and population segments may not be served by the existing waste management infrastructure. The expansion of treatment systems to these regions could potentially result in decreased methane emissions, as well as providing the benefits of improved wastewater management.

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